EFFECTS OF THREE INCUBATION SUBSTRATES

ON EMERGENT FRY OF SOCKEYE

SALMON (ONCORHYNCHUS NERKA)

RECOMMENDED:

Ronald L. Smith
Ronald L. Smith

James B. Reynolds
James B. Reynolds

Willard E Barber
Willard E. Barber
Chairman, Advisory Committee

Robert B Warden
Department Head

APPROVED:

Dean, College of Natural Sciences

W. S. Reckhow
Director of Graduate Programs

August 5, 1986
Date

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A

THESIS

Presented to the Faculty of the University of Alaska

in Partial Fulfillment of the Requirements

for the Degree of

MASTER OF SCIENCE

By

Russell R. Holder, B.S.

Fairbanks, Alaska

May 1986

ABSTRACT

Many aquaculture projects are substituting plastic for gravel as a rearing substrate for salmonid alevins. The quality of emerging fry reared on different substrates (natural gravels, plastics, and human-selected gravels) has not been compared. Sockeye salmon (Oncorhynchus nerka) were incubated in separate stream-side incubators containing rounded river gravel, fractured/crushed river gravel, and plastic Intalox saddles. Survival, length, weight, and condition of development, were similar for fry from all incubators, regardless of substrate. Median emergence timing was significantly different ($P<0.05$) for fry emerging from round gravel, angular gravel, and Intalox plastic saddles (842, 851, and 857 degree-days respectively). Natural fry had a median emergence time of 802 degree-days. Survival of incubator fry was four times that of fry in natural habitat. Fry reared in stream-side incubators were shorter, weighed less, and emerged at an earlier stage of development than fry reared naturally.

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ACKNOWLEDGMENTS

Financial support and equipment were provided by the Alaska Department of Fish and Game. I thank Ken Roberson of the Alaska Department of Fish and Game for his advice, guidance, and for allowing me the opportunity and flexibility to complete this research.

I appreciate the support and cooperation of my committee members and thank my major advisor, Dr. Willard Barber, for his helpful insight, enthusiasm, guidance, and editing. Dr. James B. Reynolds, and Dr. Ronald L. Smith reviewed the manuscript and supplied valuable advice.

Dr. Dana Thomas of the University of Alaska, and Mr. Christopher Rawson and Ms. Marianne McKean of the Alaska Department of Fish and Game advised me in data analysis and computer programming which I appreciate. Mr. Paul Misterek of the Alaska Department of Transportation and Public Facilities provided the facilities and assistance in processing the substrate samples.

I thank all the Fish and Game seasonal employees who provided field and lab assistance, especially Gary Martinek, Mark Stadtmiller, and Frank Bird.

Finally, I am especially grateful to my wife, Judy L. Holder, for her tremendous sacrifices which have made this thesis possible.

INTRODUCTION

The Copper River supports extensive commercial, recreational, and subsistence fisheries for sockeye salmon (Oncorhynchus nerka). Since the early 1970's the catches have declined with low escapements precipitating partial season closures of sockeye fisheries in 1978 and 1979. In 1980, the sockeye fishery remained closed to commercial gill net fishermen but all other user groups were allowed limited fishing. The deline in returns was attributed to the combined effects of overharvesting and erosion of spawning habitat. While most of the harvest occurs in the lower portions of the river, the majority of production is from the many lake systems in the upper Copper River.

The upper east fork of the Gulkana River between Paxson and Summit Lakes is one of several areas which contribute significantly to total sockeye production in the Copper River. In 1973 a pilot study was initiated to investigate the use of stream-side incubators as a means of increasing the natural stocks, thereby increasing the return of fish to the fisheries. The Gulkana Hatchery was a direct result of that study and was designed to enhance sockeye salmon stocks of the upper east fork Gulkana River. Since 1981 sockeye returns to the Copper River have supported all user groups due to the combination of proper management, favorable environmental conditions, and

to a limited extent the Gulkana Hatchery contribution.

The research presented in this thesis was conceived after preliminary investigations raised questions concerning the survival, timing, length, weight, and condition of development for fry emerging from stream-side incubators containing rounded river gravel and PVC Intalox saddles (Norton Co., Akron, Ohio [Roberson and Holder 1983]). While the Gulkana Hatchery uses rounded river gravel as a rearing substrate, other researchers have primarily used crushed gravel (Bams 1970, 1972, 1974, 1982; Poon 1977). In light of questions raised about the quality of fry from rounded gravel versus plastic, and the lack of research comparing different types of substrates within the same hatchery, I felt it was important to compare the survival, timing, length, weight, and condition of development, for fry emerging from rounded gravel, fractured and crushed river gravel, and Intalox saddles. In addition, the quality of fry produced in the hatchery was compared to fry emerging from the natural redd in an adjacent weired spring area in terms of survival, timing, length, weight, and condition of development to evaluate the effects of the hatchery environment on emergent fry quality.

Under natural conditions, naturally spawned eggs of all salmon species suffer approximately 75 to 95 percent

mortality between being deposited in the redd and fry emergence (Wickett 1952; Hunter 1959; Royce 1959; Foerster 1968; McNeil 1966; Ellis 1969). A hatchery on the Sacramento River in 1876 was man's first attempt at increasing adult salmon returns by increasing the number of fry produced. Documentation as early as the 1930's showed that even though survival from egg to fry in hatcheries exceeded the natural survival by many times, the corresponding adult returns were not improved (Robertson 1936; Foerster 1938).

Later, however, it was recognized that the environmental conditions of the hatchery and the natural redd differed widely. Factors which limit the survival of salmonid eggs from the freshwater redd are well documented (Wickett 1952, 1954, 1958; Neave 1953; Shapovalov and Taft 1954; Gangmark and Broad 1955; Royce 1959; McNeil 1966; Lister and Walker 1966; Foerster 1968; Bams 1969). The idea that eggs and fry raised in a hatchery were less fit for survival than wild fry arose early in this century. Robertson (1919) pointed out that hatchery fry were shorter, lighter, and had smaller eyes than wild fry. He attributed poor hatchery fry quality to the detrimental effects of light, poor water circulation, handling, altered emergence timing, and smooth hatchery troughs.

Documentation of poor adult survivals from the large numbers of low quality fry released from hatcheries,

introduced the concept that the quality (timing, length, weight, and conditon of development) of fry from enhancement programs should be similar to that of the naturally-reared fry in order to realize the increased adult returns possible from an enhancement program. Attempts to attain this goal inspired early researchers to simulate natural conditions, particularly gravel substrate. In order to simulate the natural redd in a hatchery situation, early researchers used gravel substrates in various ways with mixed results (Babcock 1911; Robertson 1919; Shapovalov 1937; Shapovalov and Berrian 1940; Carl 1940).

The first production application simulating natural conditions was the development of spawning channels in the 1950's (MacKinnon et al. 1961; Cooper 1972; Fraser 1972; Paine 1974). This was followed by the development of gravel incubation boxes in the 1960's (Bams 1967, 1970; McNeil 1968; Bailey and Heard 1973; Wilson 1974). Incubation boxes provided a savings in cost, space, and water requirements, allowing increased environmental control as compared to spawning channels.

Studies comparing fry raised in gravel substrate incubators versus wild fry support the concept that gravel substrate rearing increases the percent survival from egg to fry with little loss of fry quality (Bams 1970, 1972, 1974; Bailey and Heard 1973; Bailey and Taylor 1974;

Blackett 1974; Bailey et al. 1976; Poon 1977). Bams (1972, 1974) showed that if fry quality and time of release from gravel incubators (located on Headquarters Creek and using Headquarters Creek stock) were not significantly different from wild fry (reared in Headquarters Creek) the subsequent adult returns were in proportion to survival to the fry stage. Bams and Simpson (1977) reviewed the use of stream-side incubators and concluded that even though the information about performance of the incubators was incomplete, the available data strongly suggested that simulating natural conditions increased the percentage of adults that returned to levels that were similar or exceeded natural production.

Traditional hatcheries have improved their emergent fry quality (i.e. the survival of individual fish in terms of timing, length, weight, and condition of development) by lowering light levels, improving the water quality, and using temperature regimes that lead to release timing approximating natural timing. In spite of the fact that higher quality fry are produced when raised in or on a rugose substrate as opposed to no substrate (Marr 1963, 1965; Shumway et al. 1964; Bams 1972; Bailey and Taylor 1974; Leon 1975; Schroder 1976; Leon and Bonney 1979; Fuss and Johnson 1982), many hatcheries continue to use smooth troughs or incubators for alevin development. Alevins

have an innate righting response which they strive to satisfy from the time of hatching until neutral buoyancy is achieved (Bams 1969). If a substrate is not available to help maintain the upright position, the alevin uses up yolk energy in movement rather than growth, which results in a significant reduction in fry size (Marr 1963; Bams 1969; Hansen and Moller 1985). Three separate studies found that reduced size at emergence resulted in decreased swimming performance and increased the vulnerability to predation, which the authors considered a good indication of reduced survival potential (Bams 1967; Mead and Woodall 1968; Taylor and McPhail 1985). The percentage of malformed and/or constricted yolk sac fry was significantly reduced when raised on a rough substrate versus no substrate (Emadi 1973; Leon and Bonney 1979; Hansen and Moller 1985). A rough substrate separates the alevins into smaller clusters, which reduces alevin-to-alevin interactions (Bams and Simpson 1977).

Because gravel is heavy, awkward to handle, and needs cleaning after use, most hatchery managers have not used it as a rearing substrate. Therefore, artificial substrates (i.e. plastic saddles, bio-rings, "astro-turf", plastic grids, etc.) are being tested in "traditional" hatcheries as an alternative to smooth troughs or in simulation systems as a substitute for gravel. Advantages include light weight, ease of cleaning, ease in handling,

and higher alevin loading densities due to increased void space and higher surface area. More importantly, artificial substrates produce a higher quality fry than those reared in smooth troughs (Emadi 1973; Leon 1975; Leon and Bonney 1979; Fuss and Johnson 1982; Hansen and Moller 1985).

Biological researchers are beginning to realize that a substrate material's size and composition can have important impacts on alevin development, survival, and fry emergence timing (Shelton 1955; McNeil and Ahnell 1964; Phillips et al. 1975; Witzel and MacCrimmon 1981, 1983; Reiser and White 1983; Tappel and Bjornn 1983). Results of studies comparing fry raised on artificial substrate versus those raised on gravel substrate are published but do not include specific gravel size composition or shape, which could have influenced the results (Kepshire 1982; Leon 1982; Taylor 1984).

MATERIALS AND METHODS

The Gulkana Hatchery is located on the west bank of the Gulkana River at an elevation of 921m, in the north-central portion of the Copper River basin. It is 4.8km north of Paxson, at milepost 188 of the Richardson Highway, 3km downstream from Summit Lake (Figure 1).

The hatchery utilizes the simulation concept of stream-side incubation units, based on the Bams (1970) and Wilson (1974) design brought to the Copper River area by J.D. Solf (Ken Roberson, pers. comm.). Gulkana Hatchery has gradually expanded from a single incubator used during the 1973 - 1974 field season, to its planned capacity of 60 units (30 million eggs), realized during 1985. Eggs are taken each fall from an indigenous sockeye salmon stock, and loaded into the stream-side incubators after fertilization. Emigrant fry are captured, enumerated, and released during the spring.

The literature is inconsistent in defining early stages of salmon life history. Therefore, I define eggs as either fertilized or unfertilized salmon embryos prior to hatching. The alevin stage occurs after hatching but prior to the free swimming neutrally bouyant fry stage. The word "stress" is used in this thesis as any environmental force or variation which wouldcause the fish to function energetically, behaviorally and/or

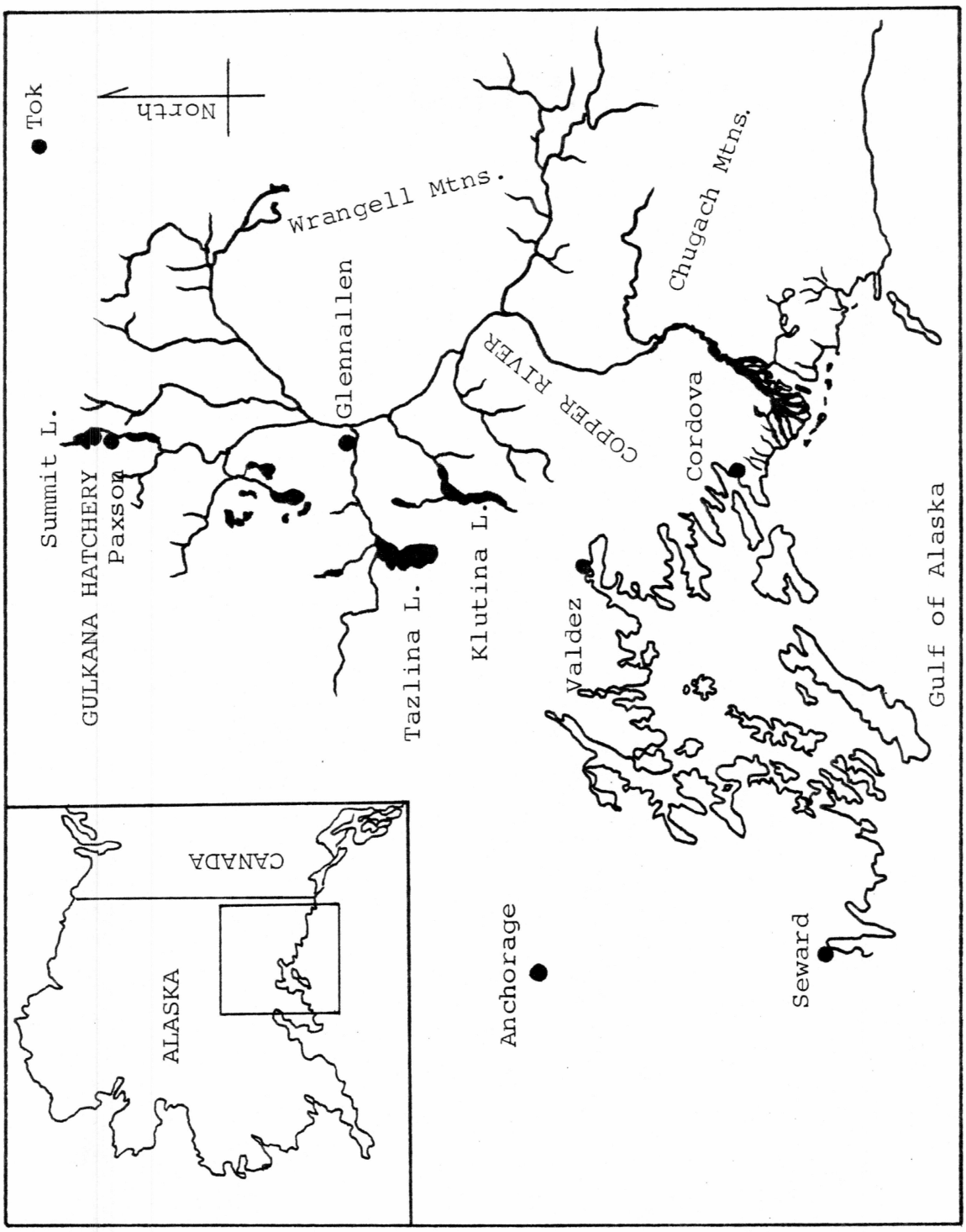

Figure 1. Location of the Gulkana Hatchery in relation to lakes and major geographic features in the Copper River watershed.

physiologically in an abnormal fashion.

Egg Collection

Male and female adult sockeye salmon were collected and spawned between 20 September and 14 October 1983. Females were killed immediately by cutting the head just behind the eye through the vertebrae. Males were killed by a blow to the head. Spawning procedures followed those of McNeil and Bailey (1975). After the eggs were fertilized had water hardened for approximately one hour, they were treated for 10 minutes with a prophylactic solution of 100ppm Betadine to prevent infectious hematopoietic necrosis virus (IHNV), then rinsed in fresh spring water. The egg collection procedures were intended to reduce stress to the adult fish and eggs, maintain broad genetic variability, and reduce the possibility of an epizootic outbreak of IHNV.

Eggs were transported to the incubators in 19-liter buckets. Total egg numbers were estimated by proportion, counting subsamples of known volume and measuring the total volume of eggs per bucket. Eggs were then loaded directly into incubators. Two types of stream-side incubator design were used in this research: production and experimental. The primary reason for employing experimental incubators was to increase sample replicates. The production units were loaded with

approximately 580 eggs/L of coarse substrate. The experimental units were loaded with 478 eggs/L of coarse substrate.

Incubator Design

Production and experimental incubation units (Figure 2) were of similar design but differed in size. Production incubators measured 1.2x2.4x1.2m, and were constructed of 19mm AC plywood. Experimental incubators measured .56x.60x.83m and were also constructed of 19mm AC plywood. Due to the smaller thermal mass of the experimental units they were housed in a protective building, while the production incubators were partially buried beside the spring water source. Each incubator had a perforated plywood false plate located 14cm above the bottom in the production units and 8.9cm in the experimental units. Water was supplied from perforated plywood headboxes buried in the spring gravel sufficiently far upstream to achieve at least 1.2m of true head. The headboxes were connected to each production unit via a 5.1cm diameter polyethylene pipe, and to each experimental unit via a 3.2cm diameter polyethylene pipe. Upwelling flow in the production units averaged 75 $\pm$15 Lpm while the flow in the experimental units averaged 45 $\pm$10 Lpm. Each incubator had a 7.6cm layer of pea gravel (approximately 1.3cm in size) over the false plate. This prevented

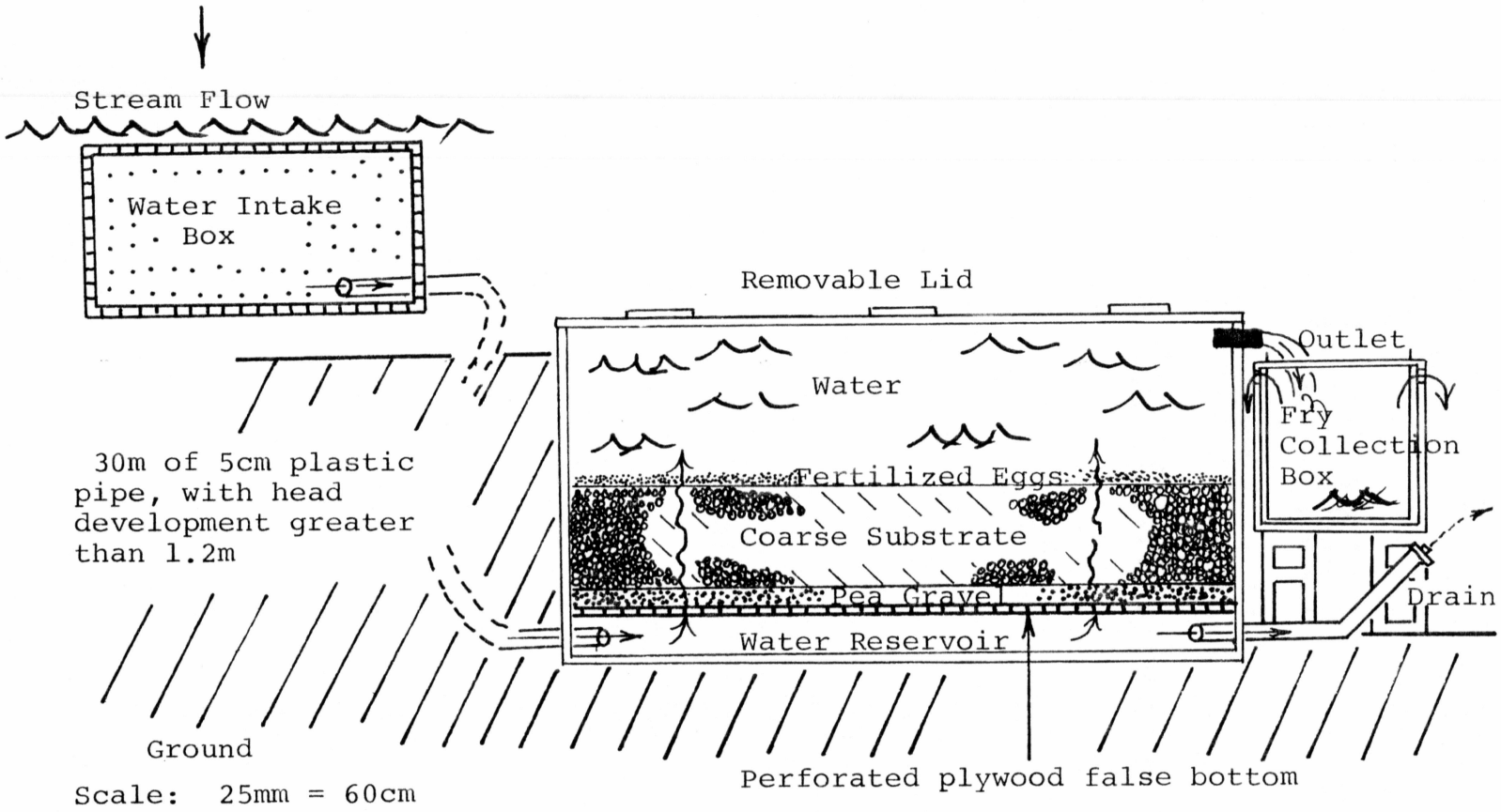

Figure 2. Diagram of plywood-reinforced upwelling production incubator used in this study showing general construction and configuration of rearing material.

downward migration of alevins through the plate, functioned as a filter, served as a water flow pressure plate, and equalized water flow within the incubator. On top of the pea gravel was 30.5cm of coarse substrate upon which the eggs were loaded and into which the alevins moved. A lid of 19mm AC plywood fit on top of each incubator (Figure 2). After the eggs were loaded into each incubator, the lid was put into place and not removed until after complete fry emergence.

Incubator Substrates

Three types of substrate were used in the hatchery incubators: 12.5mm to 38mm naturally rounded igneous river gravel, 2.24g Intalox plastic saddles (Appendix Figure A1), and 12.5mm to 38mm fractured and crushed igneous river gravel. Two 18.9 liter subsamples of each gravel substrate type were processed according to Test-7, Sieve Analysis of Fine and Coarse Aggregates in the manual "Alaska Test Methods - materials section" (Alaska Department of Transportation and Public Facilities 1980), including two samples of natural redd gravel. A comparison of substrate size composition of each gravel type is shown in Figure 3. The homogeneous plastic substrate was entirely retained by the 19.0mm sieve. Interstitial void space for each substrate type was measured by filling a 15.5 liter bucket level with sample

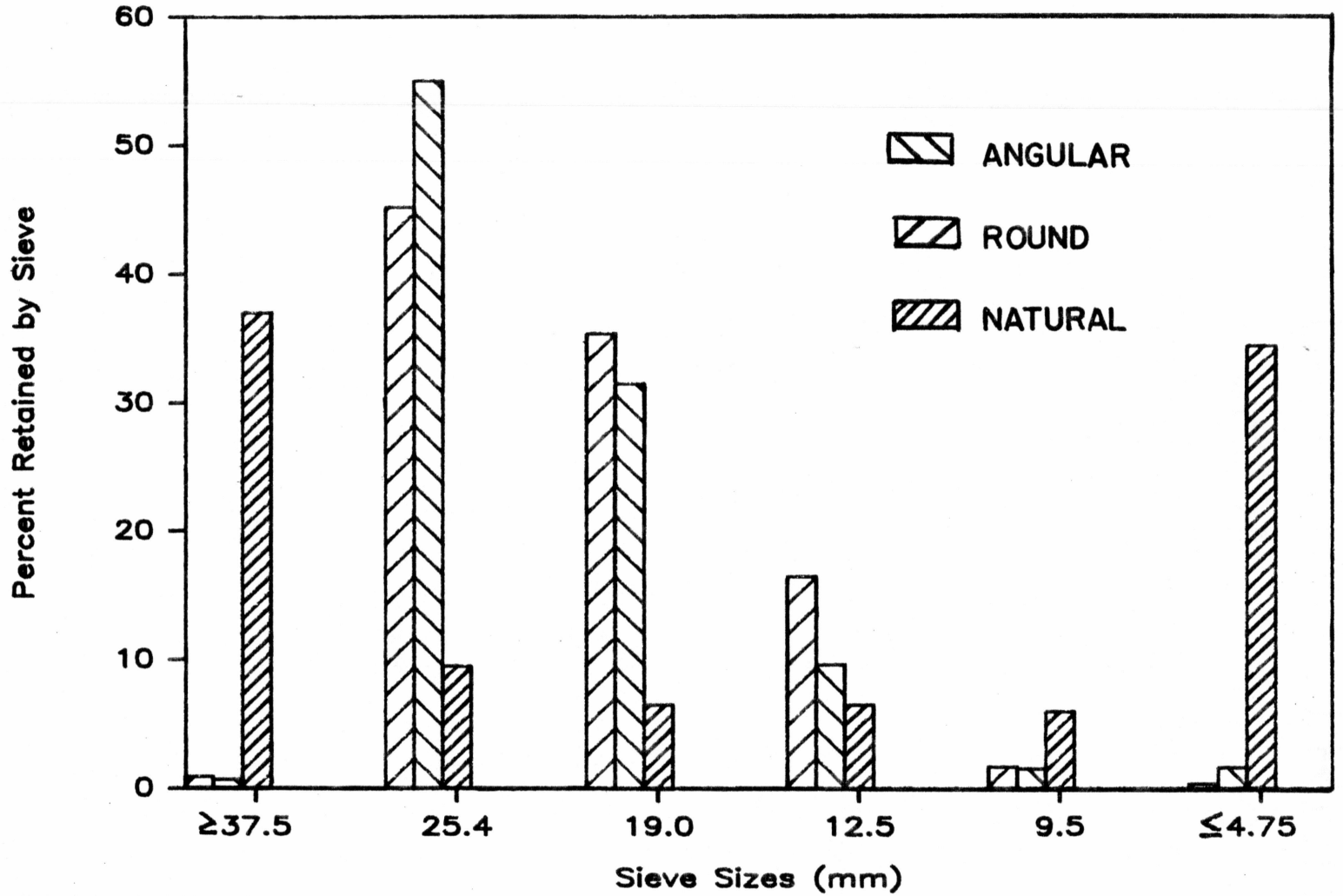

Figure 3. Comparison of incubator gravel types with natural redd gravel by particle size distribution, based on sieve retention.

substrate, filling the bucket to the top with water, and measuring the amount of water retained in the bucket after the substrate was removed. Percent mean void space in the Intalox plastic saddles, angular gravel, round gravel, and natural spring gravel, was 87.8, 43.7, 37.1, and 16.3 respectively.

Natural Spring

To determine if there was any difference in survival, time of emergence, length, weight, and/or condition of development between hatchery incubator fry and naturally produced fry, a 27m length of spring area where sockeye spawn was weired off (upper and lower weirs) as a control area. No sockeye were allowed to spawn above the control area. Two criteria were used in selecting the stream section. The area weired off would not significantly reduce available spawning ground for spawning adults, and there would be sufficient water velocity with no large rearing areas so that the newly emerged fry would be captured as they emerged. The spring area selected averaged 2.2m wide and had a discharge of 80 liter/second. The gradient was 2.7cm/m, with 2m separating riffles and pools. On 28 September 1983, five nonripe females and nine males were introduced to the weired section. Observations indicated all salmon spawned within 7 days of introduction. The fecundity/length

relationship reported by Thompson (1964) for upper Gulkana spawning stocks was used graphically to estimate the total number of eggs deposited. Since carcasses were measured mid-eye to hypural plate and Thompson's relationship was for tip of snout to fork of tail, two length conversions were performed. The first conversion was from mid-eye/hypural plate to mid-eye/fork of tail (Duncan 1956). The second conversion was from mid-eye/fork of tail to tip of snout/fork of tail (D. E. Rogers pers. comm. to K. Roberson 1974, K. Roberson pers. comm. R. Holder 1985). The number of retained eggs were counted for each carcass and subtracted from the fecundity estimate for each female. The number of eggs deposited was estimated to be 17,813 (Appendix Table A1).

Winter Monitoring

After eggs were loaded and before the fry began to emerge, incubator outflows were monitored monthly for flow, dissolved oxygen, and pH. These parameters varied little during the winter incubational period (Table 1). Each unit was treated monthly with a 3.1ppm Malachite Green prophylactic treatment until approximately one month before hatching.

Temperature unit accumulations per day for each location were recorded as degree-days (one degree day would be recorded if the mean temperature for a 24 h

Table 1. Water quality parameters of incubator effluent.

	Incubator Type	
	Production Mean and Range	Experimental Mean and Range
Flow	75 (60 - 90) Lpm	45 (35 - 55) Lpm
Dissolved Oxygen	10 (9.5 - 10.5) ppm	10 (9.5 - 10.5) ppm
pH	7.5 (7.0 - 8.0)	7.5 (7.0 - 8.0)

period was one degree centigrade). Degree-days were used to standardize and compare thermal histories between incubation units and spring study area. Degree-days for the incubators and the natural study site were recorded by Ryan continous recording thermographs. The thermograph for the incubators was located near the water intakes and the thermograph near the upper weir for the spring study site. It is assumed the temperatures as recorded are similar to those experienced by the developing fish in the hatchery incubators and natural redd due to the high rate of exchange, thermal mass, and the protective building over the smaller experimental incubators. This assumption is not entirely correct because small differences did exist between the recorded water temperatures of the hatchery and natural site on almost all days. Hatchery water gained degree-days over the natural site until the end of November. The maximum cumulative mid-winter difference was 10.9 degree-days on 5 February. The difference declined to zero by early March, after which the hatchery gained at a faster rate until a cumulative difference of 23.7 degree-days was reached by the end of May. The two cumulative heat regimes of the incubator spring and the natural test site were not statistically different (P)0.05) as analyzed by the Kolmogorov-Smirnov two-sample D statistic (Sokal and Rohlf 1981).

Fry Sampling

Fry from the incubators were collected daily in perforated sheet aluminum boxes located under the outflow from 12 April to 10 July 1984. Only fry emerging of their own volition were counted and sampled. Small numbers of fry were individually counted. As fry numbers increased, proportional volume and weight estimates were used to estimate total fry numbers. In order to establish length, weight, and condition of development relationships, samples of 50 fry were randomly selected from the incubator holding boxes at approximately 25%, 50%, and 75% of the expected 80% survival.

Fry from the weired section of stream emerged from 19 April to 10 July 1984. They were collected daily during their downstream migration in a perforated sheet aluminum weir which flowed into a catch box . The fry trap was checked at least once a day, and during peak emigration, twice a day. Fry were individually counted and samples collected at approximately 25% and 50% of those numbers expected to survive. The fry sample for obtaining length, weight, and condition of development at 75% emergence was not obtained due to problems with water entering the holding box at high velocity, which killed and deformed the fry and made them unsuitable for comparison. Samples of fry from both sources were preserved in a 5% formaldehyde solution. A preservation period of at least

6 weeks elapsed before the fish were processed, allowing shrinkage to a constant length and weight. Each fish was individually processed for fork length (±0.25mm), and wet weighed (±1mg) after blotting. Fry lengths and weights were not adjusted back to "live" values.

Bams (1970) proposed a size-independent proportionality index of relative yolk content which he called a condition of development (k_D). This index was calculated for each fish using:

$$10(\text{weight in mg})^{1/3}/(\text{length in mm}).$$

This index is not a condition factor, but an indicator of the stage of development. A high k_D value (e.g., 2.06) indicates a fish with considerable yolk reserves, whereas a low value (e.g., 1.94) indicates that the yolk is nearly absorbed. Different mean k_D values indicate different rates of development when the alevins were from the same population, lived under the same temperature conditions, and were of the same absolute age.

Data Analysis

Survival was determined by dividing the number of emergent fry by the number of eggs seeded into the incubator. Timing differences were tested by comparing the degree-days that had accumulated at the time when half of the ultimate total of fry had emerged.

To compare the effects of the three substrates on emergent fry quality, six production and six experimental incubators were randomly selected for a total of twelve incubators (two production units and two experimental units per substrate type). I grouped the incubator fry data according to substrate type in the analysis of survival and timing. Nonparametric statistics were used for the incubator survival and timing analysis due to the small sample sizes. To determine if there were significant differences (P=0.05) in survival and emergent timing between fry from different substrate types from the hatchery incubators, the Kruskal-Wallis nonparametric H test (Hollander and Wolfe 1973) was used.

The parametric two-tailed special case Student t-statistic (Sokal and Rohlf 1981) was used to test differences (P=0.05) between the single 50-percent emergence value of natural fry, and the four 50-percent values of fry from each of three incubator substrate types. I used the nonparametric Kolmogorov-Smirnov two-tailed, two-sample test to uncover differences in location, dispersion, scale, kurtosis, and skewness (Sokal and Rohlf 1981) in cumulative emergent fry distributions from incubators and the natural site.

To determine if there were significant differences (P=0.05) in length, weight, and condition of development among fry reared in the different incubator substrates, a

two-way analysis of variance (ANOVA) with two covariates and three repeated measures was used (Neter and Wasserman, 1974). The two grouping factors were incubator type and substrate. Covariates were incubator egg density and degree-days of the fry sample. The 25, 50, and 75 percent emergent samples were the repeated measures. This analysis was conducted using a BMDP program package (Dixon 1985). There was an indication that the production and experimental incubators differed slightly in their effects on fry length, weight, and condition of development. The difference was not statisically significant (P)0.05) thus I grouped emergent fry samples from the production and experimental incubators according to substrate type. Reference to "incubator" throughout the remainder of this paper includes both production and experimental units. Natural site fry were compared to incubator fry in one of two ways. If the fry from the different incubator substrates were significantly different, then analysis would proceed by comparing incubator fry from each substrate type (round, angular, or plastic) separately, to natural fry. If they were similar among substrates, incubator fry were grouped for comparison with natural site fry. Regardless of the result, incubator fry and the natural site fry were tested for significant (P=0.05) differences in terms of length, weight, and k_D, at both 25% and 50% sampling periods, using a two-tailed one-way

ANOVA (Sokal and Rohlf 1981).

RESULTS

Survival

Survival of fry from the incubation units varied from 73% to 96% (84% mean), in contrast to 20% survival from the natural spring (Table 2). Median fry survival from the round gravel, angular gravel, and Intalox saddles (84.5%, 77.6%, and 83.9% respectively), were not significantly different (P)0.05, Kruskal-Wallis H).

Timing

Fry began to emerge from both incubators and the natural spring after attaining 650 degree-days. Emerging incubator fry numbers did not rise above 1% of the eventual total per day until attaining nearly 800 degree-days, then the pattern formed a normal curve. Peak emergence varied from about 830 to 870 degree-days. In contrast, the pattern formed by the emergent natural spring fry was bimodal, a small 4 day peak of 3.5%/day occurred at 750 degree-days, with the main peak of 25% of total natural fry emigration occurring at 802 degree-days (Figure 4). The degree-days of median fry emergence for round gravel (842), angular gravel (851), and Intalox saddles (857) was significantly different (P=0.04, Kruskal-Wallis H). The emergence pattern and timing of experimental incubators loaded on the same day and

Table 2. Tabulation of incubator type, substrates, and egg density used in this research with subsequent fry survival and timing. *

Incubator # & Type	Substrate	Date Eggs Loaded	# Eggs Seeded	Density Eggs/L Substrate	# Fry Emerged	Percent Survival	Degree-Days to 50% Emergence	Calender Date of 50% Emergence
P 11	R	10/4	536704	592	515044	96	832	May 24
P 14	R	9/26&27	526028	581	450662	86	841	May 18
E 3	R	10/14	43523	573	35699	82	843	June 4
E 4	R	10/14	43523	573	36290	83	847	June 5
P 12	A	10/3	542379	599	400205	74	841	May 25
P 13	A	9/27	74525	82	69554	93	853	May 22
E 5	A	10/14	43523	573	31912	73	868	June 10
E 6	A	10/14	43523	573	35464	81	849	June 6
P 17	I	9/22	561054	619	483137	86	863	May 19
P 19	I	9/20&21	525577	580	439344	84	858	May 16
E 1	I	10/14	43523	573	35014	80	856	June 7
E 2	I	10/14	43523	573	36675	84	857	June 7
Natural Spring		10/2	17813	-----	3634	20	802	May 21

* P, Production Incubator E, Experimental Incubator
R, Round Gravel A, Angular Gravel I, Intalox Saddles

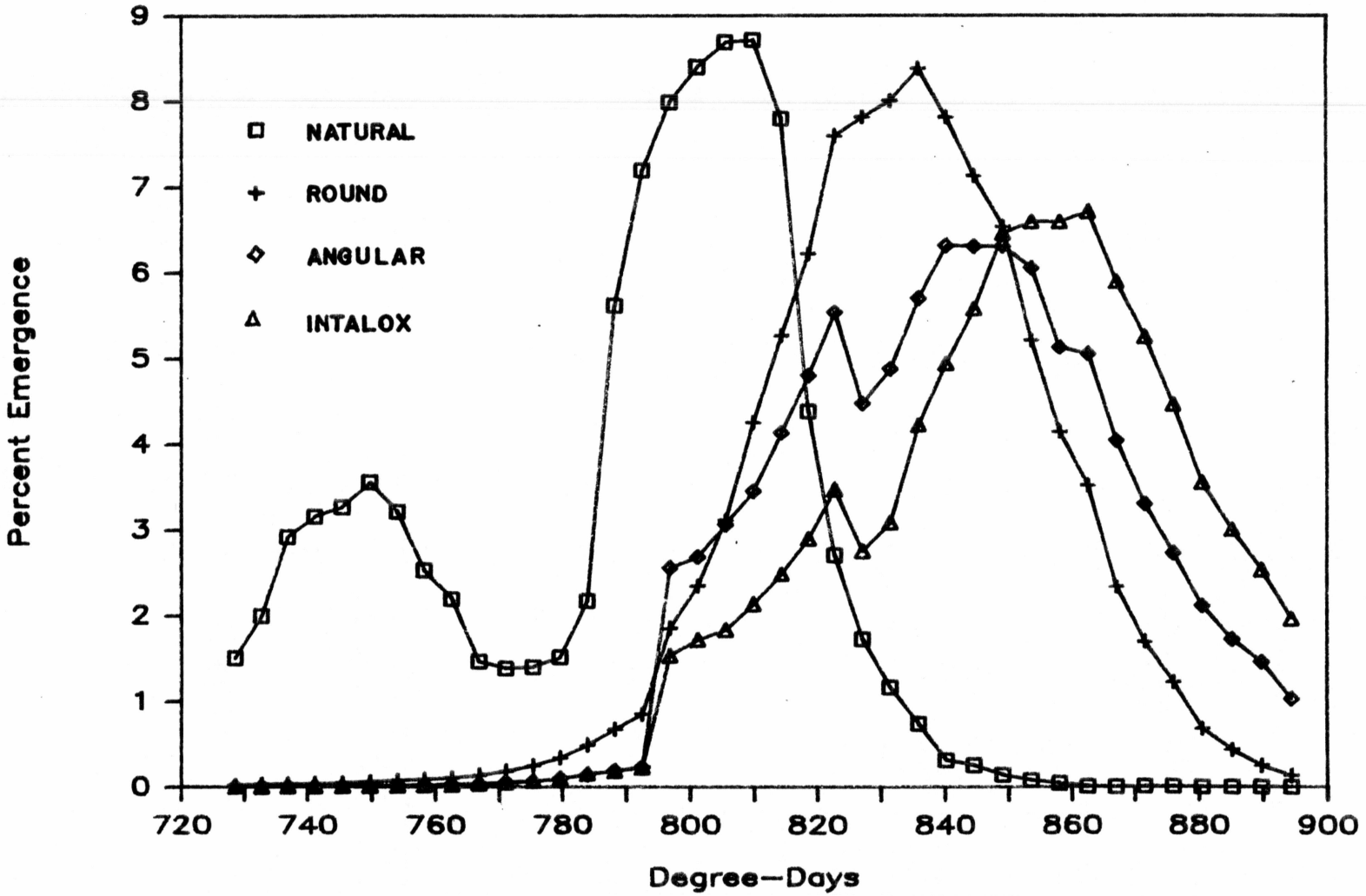

Figure 4. Daily emergence of fry from the hatchery incubators and natural fry site, smoothed by a moving average of equal weight having a function order of three.

receiving the same degree-days, show similar calendar day differences in emergence timing between round gravel, angular gravel, and Intalox saddles (June 4,5; June 6,10; June 7; respectively, Table 2). The degree-days to 50% emergence of natural spring fry were significantly different ($P<0.05$, Student t-test) from the mean 50% emergence timing of fry from round gravel, angular gravel, and Intalox saddle incubators (Table 2). Fry emerging from plastic Intalox saddles varied the most from natural fry timing in terms of mean degree-days to 50% emergence (56 degree-days and 13.5 calendar days) while round gravel fry differed the least (39 degree-days, and 9 calendar days).

Cumulative percent of incubator fry emergence with time (Figure 5) was not significantly different ($P>0.05$, Kolmogorov-Smirnov D) between the round gravel and angular gravel, or angular gravel versus Intalox saddles. However, there was a significant difference ($P<0.05$, Kolmogorov-Smirnov D) between the cumulative percent of fry emergence in round gravel and in Intalox saddles. There was a significant difference ($P<0.05$) between the mean cumulative percent emergent timing of all three incubator substrates and fry from the natural test site, with Intalox plastic saddles showing the greatest difference (Figure 5). Significant differences in median and cumulative percent emergence timing indicated that

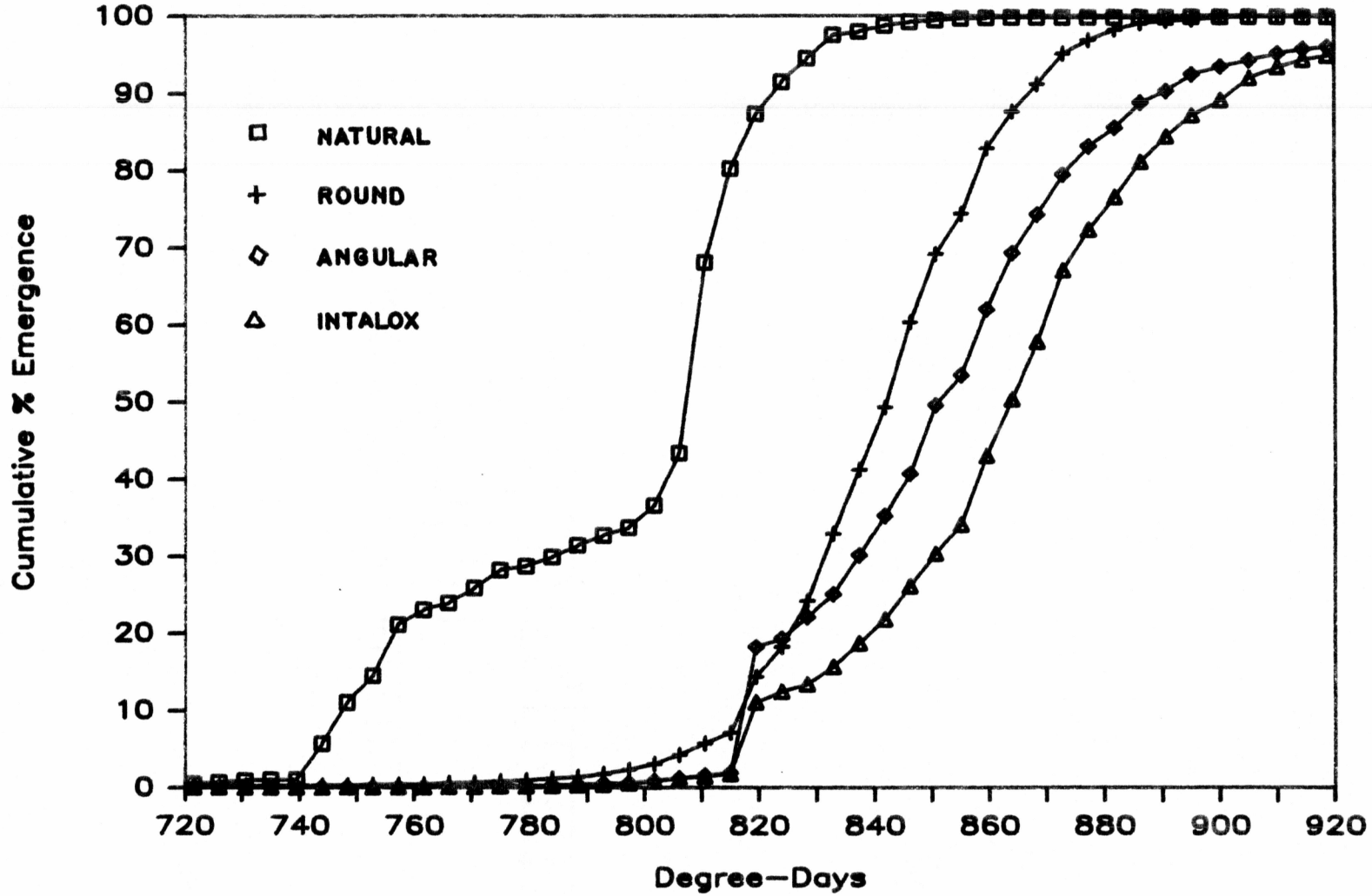

Figure 5. Mean cumulative emergence of incubator fry from the three incubator substrates and fry from the natural study site.

environmental conditions and/or fry behavior differed among the tested substrates as well as in the natural redd.

Fry Size and Condition of Development

Incubator fry were not significantly different (P)0.05, two-way ANOVA) in mean length, weight, and k_D, regardless of substrate or point in the emergence pattern (Appendix Table A2). Figures 6, 7, and 8 illustrate the random pattern of the incubator fry samples which resulted in the nonsignificant results for length (P=0.47), weight (P=0.15), and k_D (P=0.05). A two-way ANOVA indicated that incubator fry weight and k_D values significantly decreased with increasing degree days (weight P=0.04; k_D P=0.01), while fry length was not significantly affected by degree-days (P=0.32). Natural fry showed a similar pattern of changes in length, weight, and k_D with time.

Regression of fry quality parameters (length, weight, and k_D) versus degree-days showed differences in slopes which indicated that the efficiency of yolk utilization differed between alevins reared in incubators and redds. To quantify these slopes into daily growth rates between incubator and natural site fry the following technique was followed. Initial sizes and condition were calculated from regression equations in Figures 9, 10, and 11 for fry which arbitrarily would have accumulated 830 degree-days.

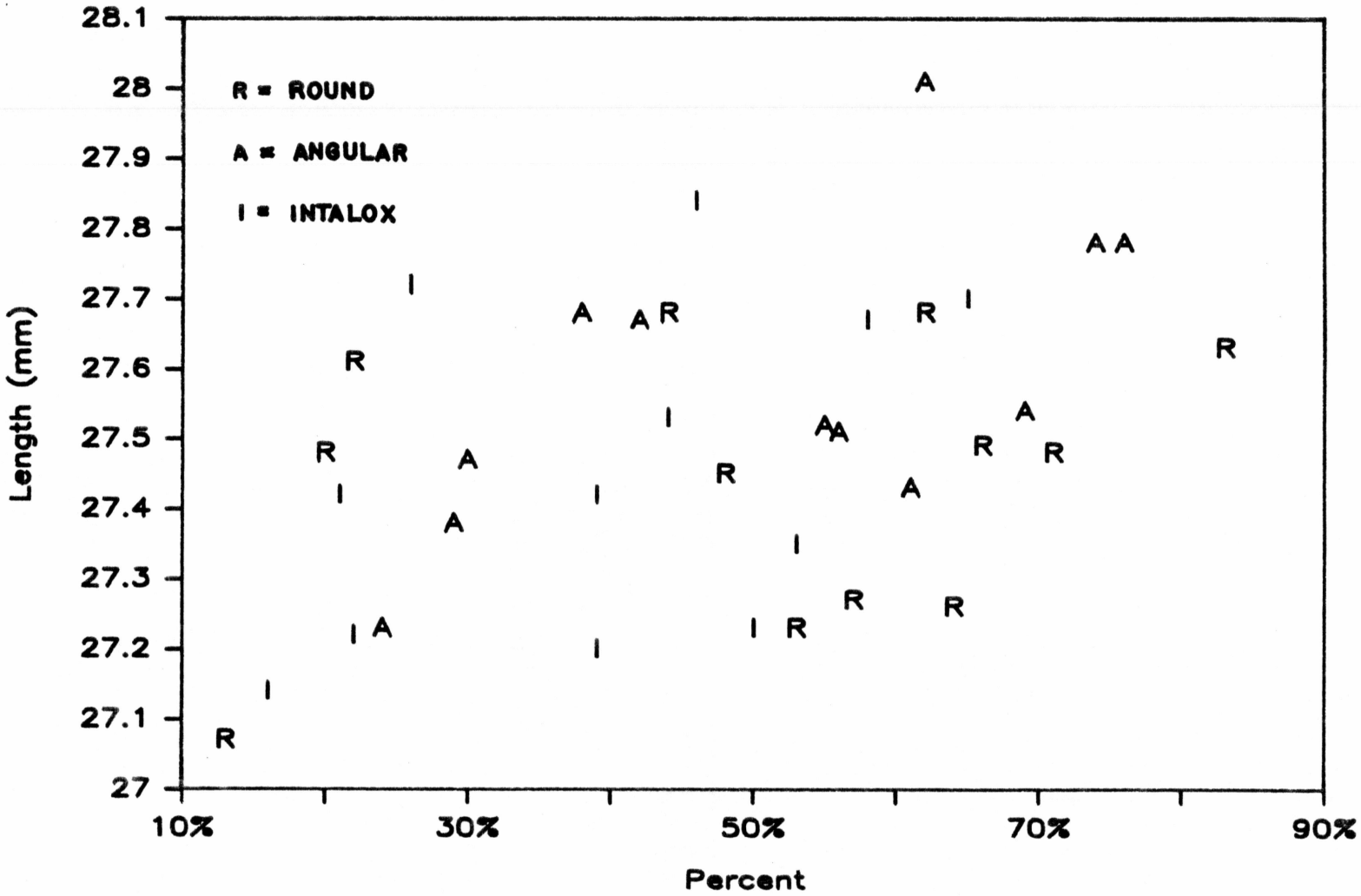

Figure 6. Mean lengths of incubator fry designated by substrate type and graphed relative to the percent emergence of the sampled unit at the time the sample was collected (P=0.47).

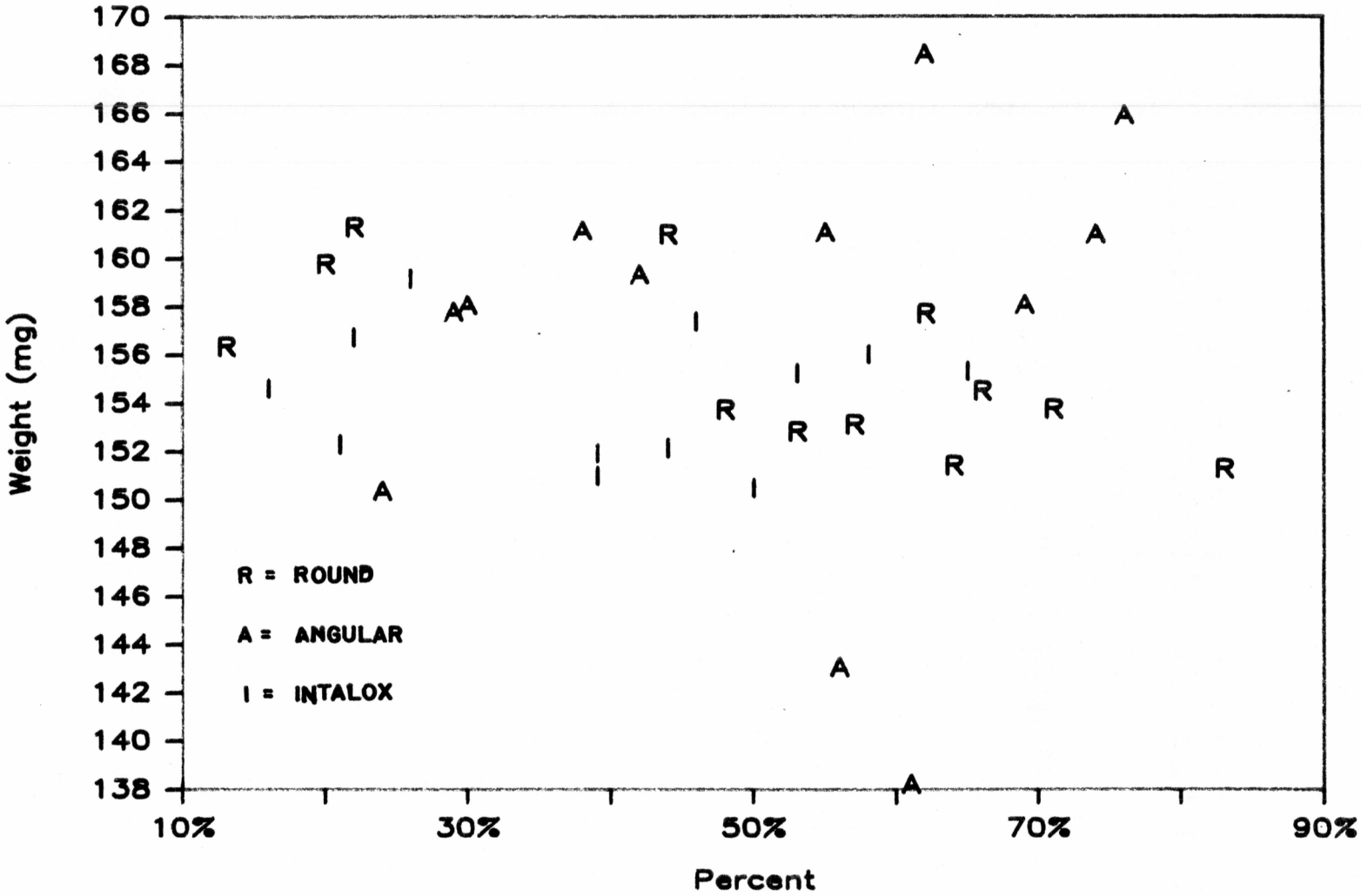

Figure 7. Mean weights of incubator fry designated by substrate type and graphed relative to the percent emergence of the sampled unit at the time the sample was collected (P=0.15).

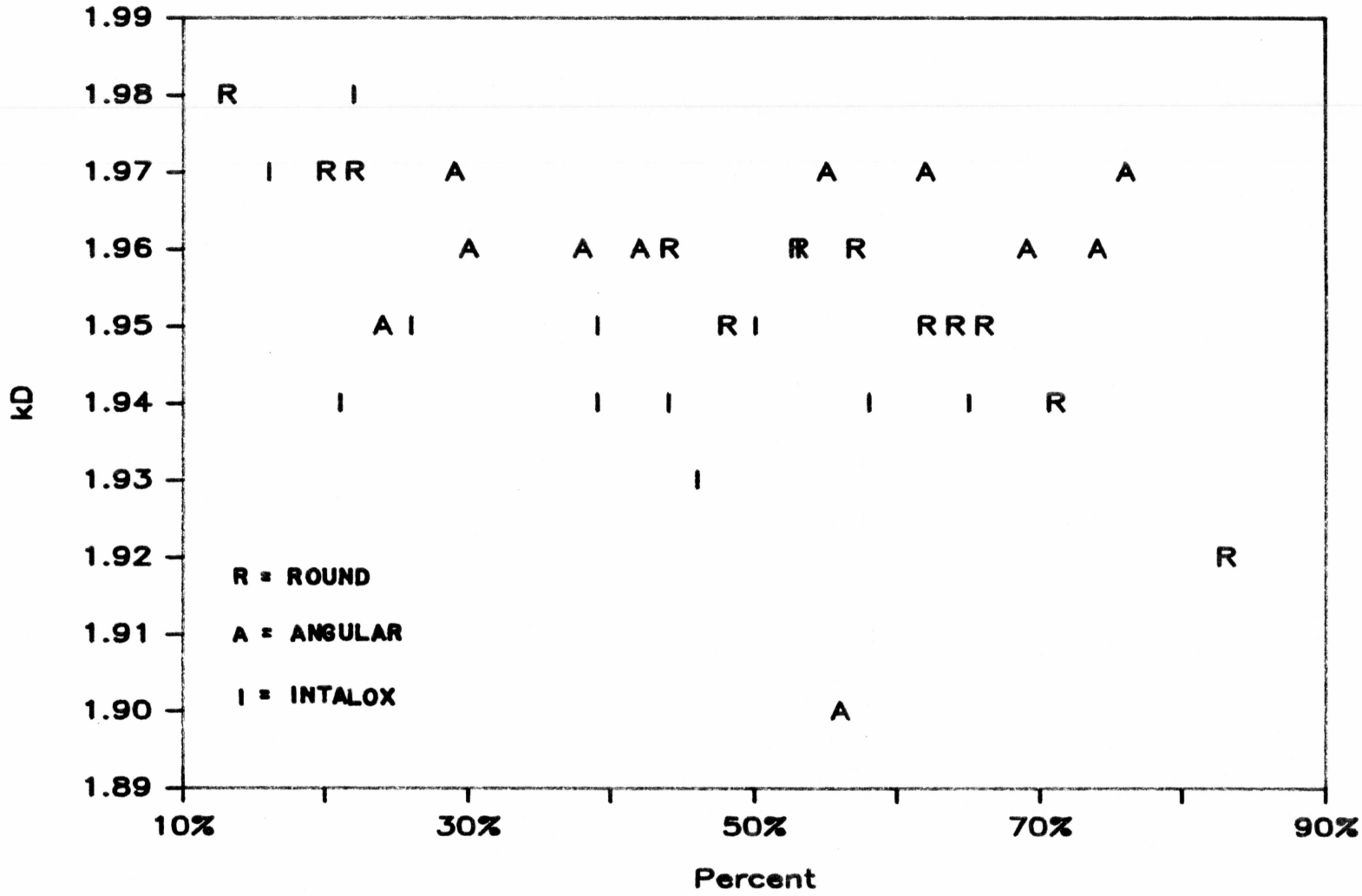

Figure 8. Condition of development of incubator fry designated by substrate type and graphed relative to the percent emergence of the sampled unit at the time the sample was collected (P=0.05).

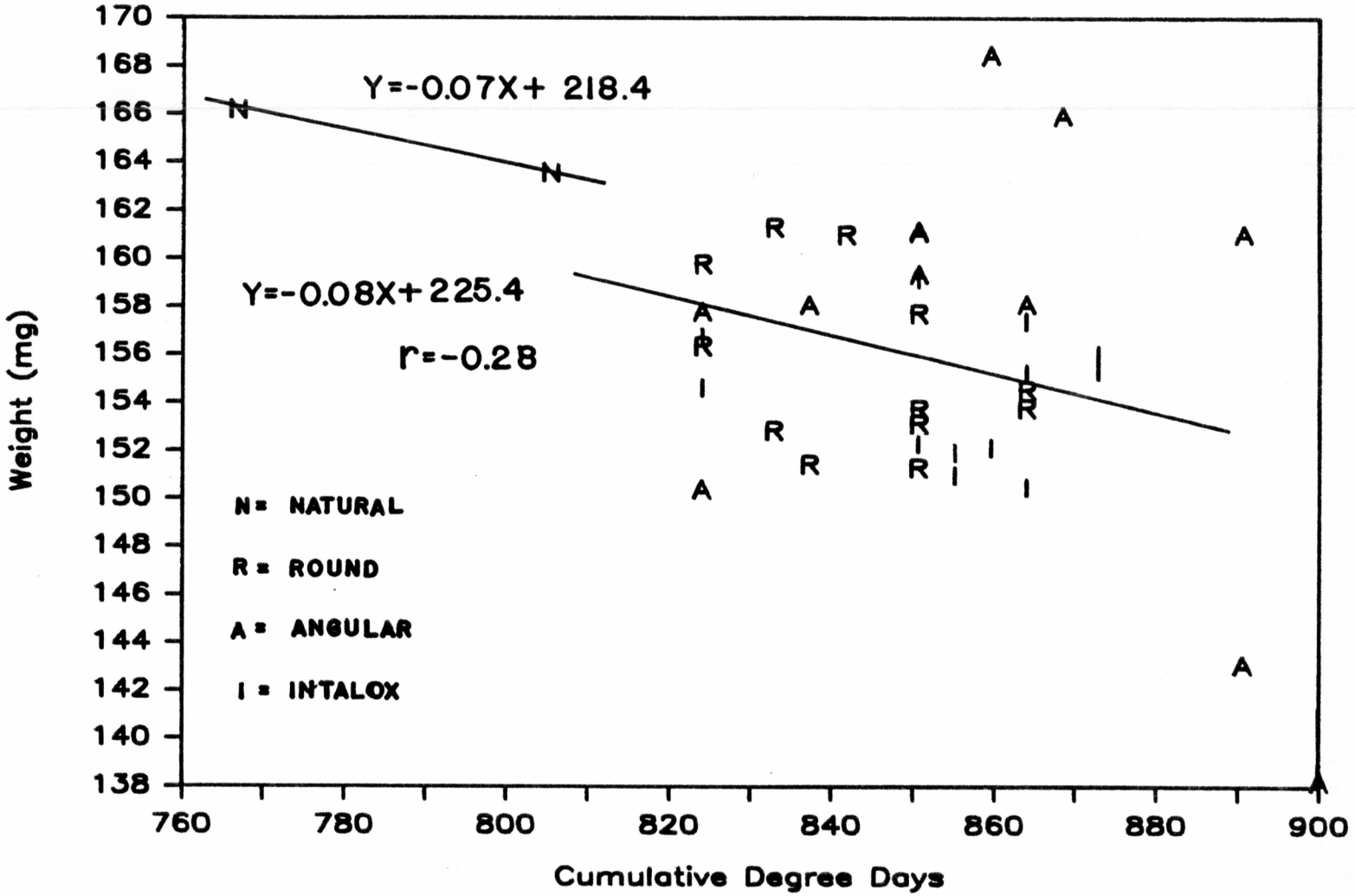

Figure 9. Plot of weight against cumulative degree-days for incubator fry samples and natural study site fry. Regression equations are shown for each source.

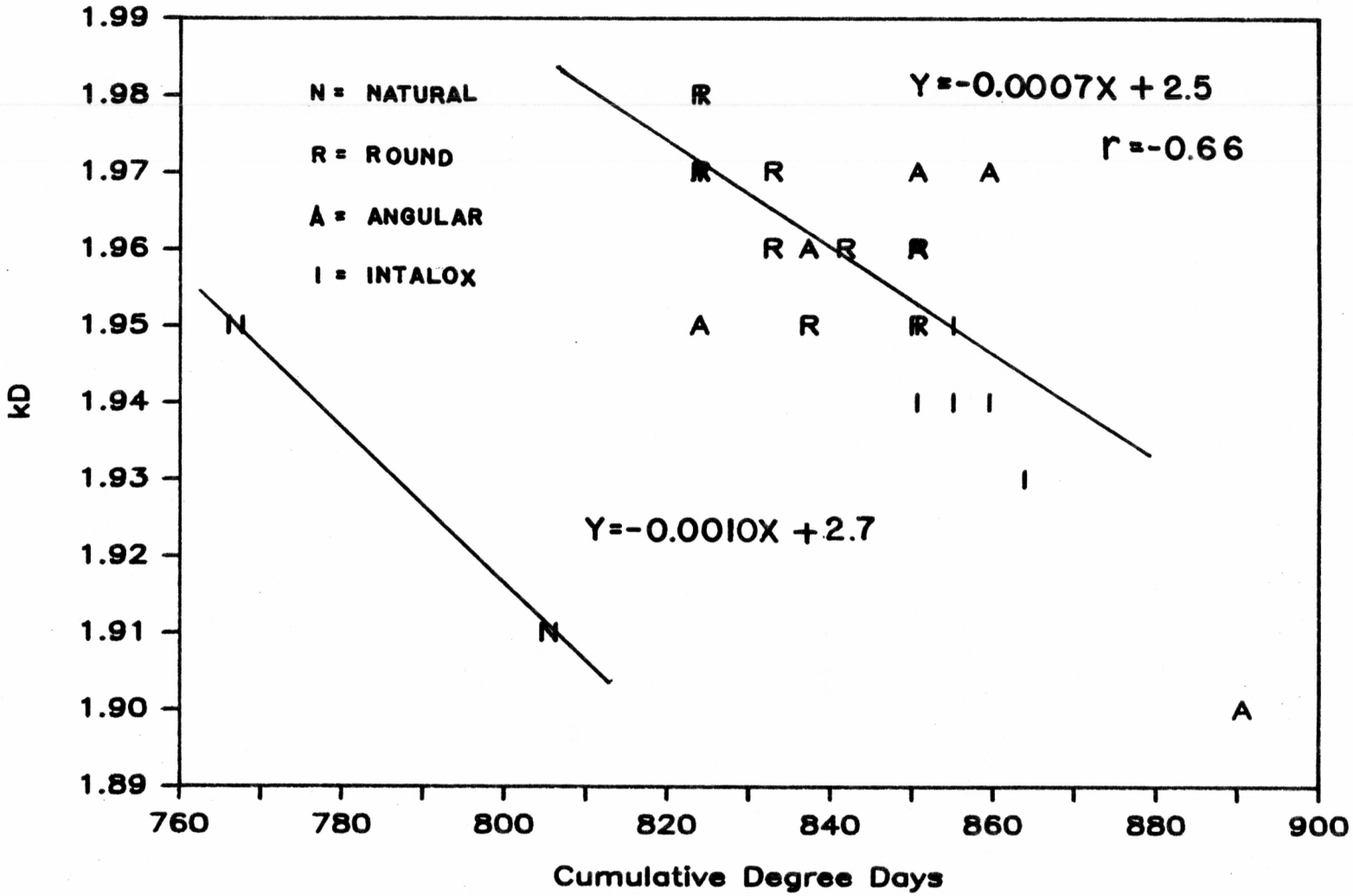

Figure 10. Plot of condition of development against cumulative degree-days for incubator fry samples and natural study site fry. Regression equations are shown for each source.

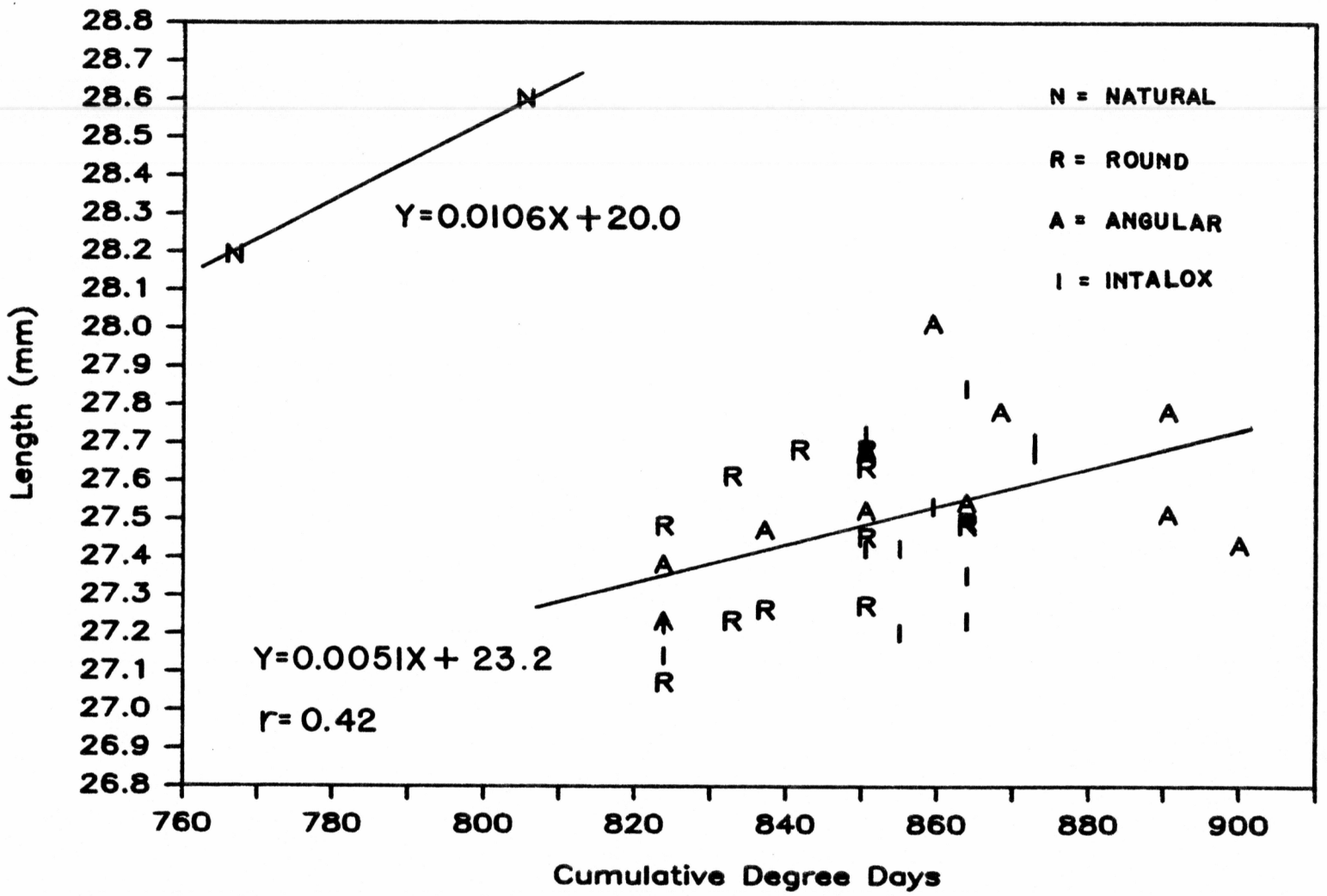

Figure 11. Plot of length against cumulative degree-days for incubator fry samples and natural study site fry. Regression equations are shown for each source.

Subsequent daily sizes and condition were calculated from these equations by substituting "830 + D4.15" for X, where D equals the number of days and 4.15 is degree-days. Daily growth rates wre subsequently obtained by subtracting each days sizes and condition from the previous day. Regression rates of weight and k_D decreased with increasing degree-days while the length relationship increased. Incubator fry lost 0.34mg/day as compared to 0.28mg/day for natural site fry. Incubator and natural site fry were just past the stage of maximum alevin wet weight, deduced from the slight negative slope of the weight regression lines (natural -0.07 and incubator -0.08; Figure 9). The condition of development decreased at a daily rate of .0029 for incubator fry and .0042 for natural site fry (Figure 10). The positive slope of the length regression lines for both the natural site (0.01) and incubator fry (0.005) samples indicated that fry were still metabolizing yolk material and had not begun to resorb body tissue (Figure 11). Incubator fry lengths were increasing at a daily rate of .02mm/day while natural fry were increasing at the rate of .04mm/day.

Both the length and condition of development regressions and rates were based on an implied accuracy (nearest 0.1mm) which exceeded the accuracy of the original length measurements (nearest 0.5mm). The length and k_D regression equations and rates within either

incubator or natural fry groups may not be real. The differences between the two groups exceeded this accuracy limitation and does imply a difference in yolk utilization between the incubator and natural fry.

Quality (length, weight, and k_D) of natural fry samples at both 25% and 50% emergence were significantly different ($P<0.05$, one-way ANOVA) from the incubator fry. Natural fry at 25% and 50% emergence were 0.8mm and 1.1mm longer, were 9.6mg and 8.5mg heavier, and emerged with lower k_D values of 0.01 and 0.04, than the corresponding mean of the incubator fry (Table 3). Incubator fry were smaller and less developed than natural site fry, after the accumulation of at least 9 additional degree-days, which leads me to conclude that the incubator fry emerged 3.4 to 13.4 days prematurely. This was calculated by subtracting the condition of development for incubator fry from natural site fry, and dividing this difference (0.01 and 0.04) by the incubator fry rate of decrease in k_D per day (0.0029) during development.

I concluded that the incubator method was responsible for an appreciable loss in potential size of emergent fry and that the average growth rate was decreased in relation to that of the natural stocks. This conclusion was reached after comparing the standardized incubator fry lengths and weights. Standardization to the same condition of development was required in order to use

Table 3. The mean lengths, weights, and condition of development (with standard deviations) for emergent fry at 25% and 50% emergence from hatchery incubators and natural study site.

Sample	Location	Degree-days	N	length (mm)	SD	weight (mg)	SD	Index (kD)	SD
25%	Natural Sp	766.8	32	28.2	0.77	166.2	16.4	1.95	0.04
25%	Incubators		640	27.4	0.94	156.6	20.7	1.96	0.04
50%	Natural Sp	805.4	49	28.6	0.73	163.5	14.9	1.91	0.03
50%	Incubators		632	27.5	0.91	155.0	20.7	1.95	0.05
25%	Natural - Incubator			0.8		9.6		-0.01	
50%	Natural - Incubator			1.1		8.5		-0.04	

N, number of fry in sample.
SD, standard deviation of mean.

lengths and weights as growth indices. Emergent fry size is dependent upon the amount of yolk originally available and the growth rate experienced during development (Gray 1928). Correction of the 25% and 50% mean weights for the 3.4 and 13.4 day premature emergence resulted in 155.4mg as compared to 156.6mg and 150.5mg compared to 155.0mg. Subtraction of the standardized incubator fry weight from the natural site fry showed there was a potential weight loss of 10.8mg at 25% emergence and 13.0mg at 50% emergence. This is a 6.3% loss at 25% emergence and 7.3% loss at 50% emergence. The 25% and 50% mean length corrections for the 3.4 and 13.4 day premature emergence resulted in 27.5mm compared to 27.4mm and 27.8mm compared to 27.5mm. Thus the potential length loss was 0.7mm at 25% and 0.8mm at 50% emergence (Table 4).

Table 4. The mean lengths, weights, and condition of develmpment for emergent fry at 25% and 50% emergence from hatchery incubators standardized to the same condition of development as natural fry.

Sample	Location	Degree-days	N	length (mm)	weight (mg)	Index (kD)
25%	Natural Sp	766.8	32	28.2	166.2	1.95
25%	Incubators		640	27.4	156.6	1.96
Standardized				27.5	155.4	1.95
50%	Natural Sp	805.4	49	28.6	163.5	1.91
50%	Incubators		632	27.5	155.0	1.95
Standardized				27.8	150.5	1.91
25%	Natural-Standardized			0.7	10.8	0.0
50%	Natural-Standardized			0.8	13.0	0.0

N, number of fry in sample.

DISCUSSION

Physical and chemical differences in the incubation environment can cause differences in survival, timing, and size of fry emerging from either incubators or the natural redd. In this study, eggs and alevins in both the stream and incubator were incubated under as similar conditions as possible in origin of eggs, spawning date, egg density, water supply, and thermal regime. The only variable in the hatchery environment was the type of substrate in which alevins developed. Incubation in the stream was under optimal conditions which included a low spawner density, a stable spring water source with constant flows, and very little temperature variation.

Survival

The major difference between the incubator substrates and the natural spawning ground was the high percentage of fine sediment (34.5%) in the natural redd passing through or retained by a 4.75mm sieve. There is an inverse relationship between the amount of fine sediment ((3.0mm) in the microenvironment and survival of the developing embryo (McNeil and Ahnell 1964; Cooper 1965; Bjornn 1969; Koski 1972; Phillips et al 1975; Tappel and Bjornn 1983; Witzel and MacCrimmon 1983). Most of the above studies have attributed low embryo survival, in substrates with

a large percentage of fines, to entrapment and or decreased gravel permeability. Decreased permeability results in low water flows around the embryo causing a decreased oxygen supply and accumulation of toxic metabolic wastes. Cooper (1965) suggested that gravels finer than 3.36mm may create lethal pressures due to compression. Gravel incubators containing large amounts of fine sediment (41.3% retained by a 4.7mm sieve and 5.4% retained by a 2.3mm sieve) have produced low percent survival from egg to fry (18.1%, Ginetz 1976). The results of this study demonstrate that none of the three rearing media used in the hatchery incubators deleteriously affected the egg to fry survival. Survival 4 times (84% versus 20%) that of the naturally spawned eggs was achieved consistently due to the combination of constant water supply and elimination of the fines which occur in the natural redd. Other authors have reported similar egg to fry survival ratios with gravel incubators over naturally spawned eggs (Bams 1972, 1974; Bailey et al. 1976).

Timing

Timing of the natural emergent fry has been determined by years of natural selection balancing the two opposite pressures of early lake entry and late lake entry for optimal survival in this nursery area. Early lake entry

is advantageous when sufficient food is available because it increases the length of time for feeding, resulting in a larger fish, which has a survival advantage over smaller fry entering the lake later (Bams 1969). Early lake entry fish may not survive if the spring plankton blooms have not begun. Late lake entry balances 1) decreased survival potential if food is available early, due to a shorter growing season, versus 2) increased probability of survival by entering the lake when a food supply is assured (Bams 1969). These two pressures act to increase the likelihood of fry emergence coinciding with first food availability (Bams 1969). Because alevins reared in a stressful environment retain their natural emergence timing while sacrificing growth in size, Bams (1969) theorized that retention of natural emergence timing was less likely to subtract from the fishes survival potential than any other combination of adaptive responses. Evidence by Gray (1928) supports this theory - normal but smaller fry were formed at the normal time, after removal of part of the yolk at an early stage. Such relationships indicate that any propagation program must not alter the natural optimal average release date or decreased survivals must be expected.

Even though time of fertilization and temperature regimes were accounted for in all treatments, it is important to compare the physiological parameters of rate

of development, growth rate, and stage of development at emergence, for meaningful interpretations of timing, length, weight, and k_D differences.

Rate of Development

Rate of development is determined primarily by temperature (Kinne and Kinne 1962; Garside 1966; Peterson et al 1977; Heming et al 1982). As long as temperatures are within the normal range, the higher the temperature, the faster the fish develops. Temperature regimes of the individual incubators were assumed to be similar, due to the thermal mass of each production incubator ($3.6m^3$), and the protective building over the experimental incubators. Reduced developmental rates of alevins are caused by low to intermediate levels of oxygen concentrations (Alderdice et al 1958; Garside 1959, 1966; Silver et al 1963; Shumway et al 1964; Brannon 1965; Hamor and Garside 1977), and high concentrations of ammonia (Fedorov and Smirnova 1978). If temperature regimes are similar and rates of development are different in the hatchery and/or the redd, then chemical factors are considered the most probable cause.

In this study, degree days for median emergence timing were significantly different between the three incubator substrates. Fry emerged 2 and 4 days later from the angular and plastic saddle substrates than round gravel

substrate. Taylor (1984) found that fully developed fry emerged three days later from plastic substrates than from river gravel. If the developing embryo had been using energy in response to a stress, I would have expected a significant difference in fry size. Since this was not the case, and the fish emerged at similar stages of development (i.e. fry from angular and plastic saddles took a longer time to develop than fry from round gravel), I concluded that differential rates of development must have occurred within the three tested substrates.

There were statistical differences ($P<0.05$) between natural and incubator fry in terms of length, weight, condition of development, and median time of emergence. A possible explanation involves the fry capture date. Fry from the incubators were allowed to emerge of their own volition. This is in contrast to Bams (1970) who "scooped" the fry from the incubators. Large numbers of incubator fry were observed swimming in the water column above the coarse substrate, with no directed swimming toward the outflow. It appeared that fry were content to swim in the unit until caught in the outflow current. Additional time within the hatchery incubators would change the time of emergence, but does not account for the different timing from the three incubator substrates, nor does it explain the loss of potential size, since the incubator fry had not begun to resorb body tissue.

Differential emergence timing between the natural fry and the hatchery fry may be partly attributed to the natural fry having little opportunity to reenter the gravel after entering the flowing spring water, due to the gradient and the lack of rearing pools. This does not explain why naturally reared fry were consistently larger, heavier, and had a lower condition of development with less accumulated degree-days.

It was calculated that incubator fry emerged about 3.4 to 13.4 days prematurely. This agrees with research by Bams (1970, 1972, 1974), who stated that the deep gravel substrate incubator hatchery method inherently caused premature emergence of hatchery fry, an average of 10 days less than that of natural fry. Adding the premature emergence days (k_D) of 3.4 and 13.4 days to the actual difference in median degree-days (round 9.6, angular 11.7, and Intalox 13.3 days), the total degree-day difference between naturally reared fry and incubator fry expanded to between 13 and 23 days for round gravel fry, 15 and 25 days for angular gravel fry, and 17 to 27 days for fry reared in plastic saddles. I conclude that developmental rates between the hatchery and the natural environment were significantly different. This implies that combinations of water flow and fish densities used in this test were not adequate in preventing stress problems, as revealed by the differential developmental rates.

Growth During Incubation

Size of fry upon emergence depends upon the microenvironment in which the egg and alevin develop. A fixed quantity of yolk is the only energy source available during development to meet maintenace, activity, and growth needs. Any diversion of yolk energy from normal development due to a stress response will reduce the emergent fry size (Brannon 1965; Bams 1969). If a newly hatched alevin in a natural redd does not encounter unfavorable conditions, it will remain in the crevice where it hatched until it is ready to emerge (Bams 1969). If the conditions are unfavorable, alevin behavior is negative phototactic and positively geotatic until emergence (Bams 1969), which means the alevin swims down if it leaves the crevice where it hatched. Our hatchery procedure is to load the eggs on top of the coarse substrate. Thus, upon hatching, alevins must swim down in order to find a crevice to develop in. In this situation energy is expended for movement rather than growth.

Where no substrate (hatchery tray or trough) or minimal substrate is present, alevins have been documented to exibit "clumping" behavior (Leon 1975, Bams 1982, Hansen and Moller 1985). This clumping behavior may cause localized oxygen depressions and/or metabolic waste accumulation (Leon 1975; Hansen and Moller 1985;). Bams

(1969) presented evidence which suggested that the primary stimulus for greatly increased activity was increasing carbon dioxide levels. Growth of larval fishes has also been shown to be reduced when fish are reared in a low to intermediate supply of oxygen (Silver et al 1963; Shumway et al 1964; Brannon 1965) i.e. a smaller emergent fry at an earlier stage of development.

General

Causes of localized oxygen depressions and or accumulated metabolites are directly related to alevin behavior within a substrate. The large void space of the plastic saddle substrate offers little resistance to alevin downward movement, tending toward mass clumping in the bottom of the incubator. The lesser void space of the gravel substrates offers smaller crevices, which separates the alevins, allows less alevin interaction, and decreases clumping opportunity.

Effluent oxygen levels do not indicate oxygen availability to the developing egg or alevin. Bams (1982) showed that chemical conditions within a substrate can be more extreme than those in the water layer above the substrate or in the effluent flow. Bams (1982) found that dissolved oxygen along the bottom of deep gravel incubators was consistently 1.1 to 1.78 mg/L lower than the oxygen level in the upper water layer. This

difference depended on flow rate, fish density, and developmental stage. Bailey et al. (1980) documented that as alevin density increased, fry size and emergence times decreased, and suggested that limited metabolism due to decreased oxygen concentrations and increased total ammonia production within the incubators was the cause. Even though oxygen measurements of the hatchery water effluent were at saturation throughout the developmental period, I speculate that alevins absorbed their yolk at different efficiencies within the different substrates due to localized depressions of oxygen and or accumulations of metabolites.

Brannon (1965) suggested that the often-reported accelerated development among hatchery versus natural alevins was most likely caused by nonsaturated oxygen levels in the natural redd as compared to the hatchery saturated environment. I think in this case the reverse may be true. Saturated hatchery water becomes oxygen depleted and metabolites increase in the alevin microenvironment in direct relation to the void space of the rearing substrates. The situation is more acute in larger void space substrates due to the larger numbers of fry which can inhabit a single void. Increased numbers of fry inhabiting a single void would tend to cause lower oxygen and higher metabolite levels in that particular void which would in turn cause decreased rates of

development, evidenced by lengthened median emergence dates. A significant wall effect (personal observation) may explain why there was no significant decrease in oxygen levels in the effluent flow from the incubators. Oxygen saturated water passing along the incubator wall and out the outlet would not be a true representation of the oxygen levels experienced by the eggs and alevins within the substrate. The high quality water available to the naturally spawned eggs and alevins, combined with very low embyro densities, would increase the developmental rate and allow the most efficient yolk utilization.

Table 5 is a comparison of egg seeding densities and water flow rates in this study compared to those of other studies which present information on the quality of emergent fry from stream-side incubators. In order to compare these studies by a standard number (eliminate incubator size effects), egg densities and water flow rates have been standardized by volume of substrate material used in each study. These two numbers were then divided to attain a nonvolume density estimate of eggs/L/min. Even though other authors were not using sockeye, and some of the results may be attributed to the species and stocks used, these other studies present useful guideline information. Bams (1974, 1972) used eggs at one-third the density of the Gulkana production units and reported no difference in growth rates and yolk

Table 5. Comparison of egg densities and water flow rates per incubator substrate volume used in this study and by other authors.

Author	Species	Incubator Size (m)	Substrate	Substrate Volume (m3)	No. Eggs	No. Eggs/ m3 of substrate	Water Flow (L/min)	Flow (L/min per m3)	No. Eggs (eggs per L/min)
Present Study	sockeye	1.2x2.4x1.2 (production)	Round Gr Angular Gr Plastic	0.86	500000	581395	75	87	6667
Present Study	sockeye	.56x.60x.83 (experimental)	Round Gr Angular Gr Plastic	0.1	43500	435000	45	450	967
Bailey et al 1980	pink	.3x.3x.3	gravel	0.015	1600	106667	0.8	53	2000
				0.015	6400	426667	0.8	53	8000
				0.015	12800	853333	0.8	53	16000
				0.015	25600	1706667	0.8	53	32000
Bailey et al 1976	pink	1.2x1.2x1.2	gravel	1.25	150000	120000	75	60	2000
Bailey and Taylor 1974	pink	1.2x0.91x0.91	Round Gr	0.57	112200	196842	56	98	2004
				0.57	53600	94035	28	49	1914
				0.76	56100	73816	28	37	2004
				0.76	112100	147500	56	74	2002
Bams 1982	chum	.3x.6x1.2	Angular G	0.14	16000	114286	8	57	2000
				0.14	32000	228571	16	114	2000
				0.14	32000	228571	16	114	2000
				0.14	16000	114286	8	57	2000
Bams 1974	pink	1.2x2.4x1.2	Angular G	2.3	80000	34783	35	15	2286
Bams 1972	pink	1.2x2.4x1.2	Angular G	2.3	75000	32609	35	15	2143

conversion efficiency between fry from gravel incubators and wild emergent fry stocks. Bams (1982) reported fry sizes were consistently larger from high flow units than low flow units, even though the egg density and flow rates convert to the same number of eggs/L/min. Bailey and Taylor (1974) used rounded river gravel substrate, and produced incubator fry which were smaller, emerged 3 days earlier, and had decreased rates of development and growth as compare to natural fry, even when eggs/L/min were similar to Bams (1972, 1974). Bailey et al. (1976) produced incubator fry which emigrated seaward two weeks earlier than creek fry, were three days premature in terms of k_D, and were shorter but heavier than creek fry. Bailey et al (1980) presented data for pink salmon which indicated that reduction in fry size and early emergence was caused by depletion of oxygen levels to less than 6mg/L resulting from high loading densities (greater than 16000 eggs/L/min).

Gulkana production incubators have the highest egg density per L/min of water flow per volume of substrate when compared to other experiments, but the experimental incubators have the lowest (Table 5). Due to the high flows available in the experimental units, it would not be expected that a loss of size and altered developmental rates would occur. Fry from the experimental incubators are similar in all aspects to the fry from the production

units in terms of increased survival, altered timing, reduced size, and delayed rates of development and growth, even though they were at one sixth the egg density and flow of the production units. This supports my hypothesis that alevins migrated to the bottom of the coarse substrate after hatching and that actual alevin densities and flow within the substrate were dependent on the void space. Densities and flows within the production incubator substrates are probably contributing to the problems of premature emergence, and decreased developmental and growth rates, but based on the available data, unless sockeye salmon rates of development and growth are influenced to a much greater degree by decreased oxygen, and increased carbon dioxide and ammonia than pink salmon, there are other contributing factors.

The ultimate test of any hatchery method is the adult returns. If the gain in survival during the egg and alevin stages carries through to the adults, the hatchery method is fulfilling the desired goal. Since I can not compare adult returns from these treatments, evaluation of the potential hatchery contribution are based on what other authors have reported as adult survival ratios for similar experiments. The method of comparison involves a concept termed "gain ratio". The survival of hatchery fish (S_H) is divided by survival of wild fish (S_W) at both the fry stage and returning adult, thus there are two

separate gain ratios (fry and adult) for each release. A small decrease in gain ratio from fry to adult means the hatchery method was successful in producing viable fish, while a large decrease (greater than 50%) means that hathery fish did not survive at the same rate as wild fish. Bams (1972) reported a decrease of only 1.16% between the gain ratios of fry (6.04) and adult (5.97) stages, even though hatchery fry at emergence were 2.17% shorter, 2.19% lighter, and less advanced than wild fry by 6 days growth. Bams (1974) documented a 4.6% decrease in gain ratio of fry (3.63) and adult (3.46) stages, even though hatchery fry were 2.16% shorter, had similar weights, and fry emerged 11 days prematurely. Bailey et al. (1976) reported a 94% loss between the fry gain ratio of 9.4, and the adult ratio of 0.79. Fry were only 0.16% shorter, 2.8% heavier, and only three days earlier in development, but they emigrated 2 weeks earlier than creek fry.

The gain ratio of 4.2 at the Gulkana Hatchery fry stage probably would be reduced at the adult stage because hatchery emergent fry were 7% lighter, 2.8% shorter, emerged 3.4 to 13.4 days prematurely, and delayed emigration at least 9 days compared to natural fry. I do not believe we would see as severe a reduction in adult survival as Bailey et al. (1976) reported, because their fry emerged two weeks earlier than creek fry and probably

were limited by food availability. Gulkana Hatchery stocks should see a larger reduction in gain ratio than Bams (1972; 1974) reported due to the loss of potential size, and decreased rates of growth and development, none of which showed up in Bams' research. A reduction in the gain ratio of between 10% to 30% at the adult stage is probable (adult gain ratio of 3 to 4).

Recommendations

The rearing media for sockeye alevins must take into account biological effects, initial cost, availability, ease of cleaning, and ease of handling. The continued use of a heterogeneous mix of igneous rounded river gravel in the size range of 12.5mm to 37.5mm is recommended. Of the three substrates tested, round gravel gave a median emergence date most similar to that of fry reared in natural substrate. Initial cost at the factory for the plastic saddle substrate is 30 times that of gravel substrate delivered on site. Even though gravel is heavy and awkward to handle, the amount of time that it takes to clean a plastic saddle substrate incubator is usually longer due to the dead egg material which sticks to small holes and edges of saddles. Mechanized methods for cleaning gravel could be be developed which would be economical, practical, and less labor intensive.

Bams and Crabtree (1976) did not recommend round river

gravel in the single 19mm size because alevins tend to fall through the smooth passages and accumulate in large densities in the bottom of the incubator. They suggested, as did Bams and Simpson (1977), homogeneous crushed gravel (19mm-38mm) for ease of sorting and maximum void space. They suggested the flat surfaces and exposed ridges would aid the alevins in retaining their preferred upright position. Bams and Crabtree (1976) did suggest that rounded gravels might be used if finer material were added to fill the larger interstitial spaces. I found that the increase in void space of 6.6% from rounded gravel to crushed gravel influenced fry behavior enough to cause a two-day delay in median emergence timing from that of fry reared in rounded gravel. Smaller crushed gravel could be added to fill in interstitial spaces of the crushed gravel used in this study to reduce the amount of void space. Shumway et al. (1964) found that a mixture of large and small glass beads (porosity 0.3) produced the largest fry as compared to fry reared separately in cylinders containing homogeneous large or small beads (porosity 0.4). Their explanation was that increased mean velocities around the embryo magnify with decreasing porosity, providing a more favorable growth environment.

Additional research needs to be done to determine if low oxygen levels and/or metabolites are indeed the causes of the decreased developmental rates observed in the

Gulkana Hatchery incubators. I suggest that immediate concerns are to decrease the wall effect within incubators, and determine the proper combination of fish density and water flow which will not significantly affect the rates of development and growth.

SUMMARY

1. Survival of fry from constructed incubation units varied from 73% to 96%, which was four times higher than the 20% fry survival from the natural site.

2. Median emergent degree-days were significantly different among incubator substrates: round gravel, angular gravel, and Intalox saddles (842, 851, and 857 degree-days respectively). Degree-days at median emergence for natural fry totalled 802.

3. The mean length, weight, and condition of development of incubator fry were not significantly different regardless of the rearing substrate.

4. The mean length, weight, and condition of development of natural fry were significantly different from incubator fry at both 25% and 50% of total emergence.

5. The difference in emergent k_D values indicates that incubator fry migrated 3.4 to 13.4 days prematurely.

6. Compared to naturally incubated fry, incubators caused an appreciable loss in potential size of the emergent fry and a decrease in the average growth rate.

7. Fry emerging from the different incubator substrates experienced different rates of development.

8. The developmental rates between the incubators and the natural environment were significantly different.

9. Because differing amounts of void space created differences in alevin density, a probable cause for differential rates of fry development could be lower oxygen and higher carbon dioxide and ammonia levels within the larger void space microenvironment of incubators.

10. The use of igneous rounded river gravel (12.5mm - 37.5mm) as a rearing substrate should be continued because the timing of fry emergence in this substrate is the most similar to that in the natural substrate among the three substrates tested in this study.

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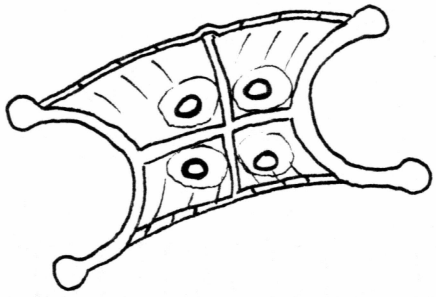
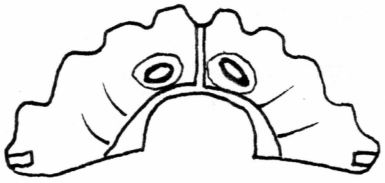
APPENDIX

Actual Size

Top View



Side View



End View

Specific gravity	1.13 ± 0.02
Weight of one saddle	2.24 g
Volume of one saddle	1.98 ml
Void space	± 92%
Dry weight of 1 m^3 of saddles	91.3 kg

Figure A1. Polypropylene Intalox plastic saddle diagram and specifications. One cubic meter of saddles delivered by the manufacturer occupies approximately 1.28 m^3 of space in the incubator unit.

Table A1. Conversion of female sockeye salmon carcass lengths (from mid-eye - hypural plate to tip of snout - fork of tail) in order to estimate total eggs deposited at the natural study site.

Original female length measurements (mm) *

ME -HP
449
483
508
529
527

First Conversion (ME - HP) 1.099 + 5.364 = (ME - FT)

(ME - FT)	
499	Duncan, 1956
535	
563	
607	
584	

Second Conversion (ME - FT) 1.0794 + (-4.889) = (TS - FT)

(TS - FT)	
534	Rogers, Donald E., 1974
573	(personal communication
604	to K. Roberson,
651	K. Roberson to
626	R. Holder 1985).

Fecundity estimated graphically as per Thompson, 1964.

Estimate from graph	(mm)	# Eggs	# Eggs Retained	Eggs Deposited
	534	3530	7	3523
	573	3710	22	3688
	604	3860	1239	2621
	651	4000	1	3999
	626	3985	3	3982
	Total Eggs Deposited			17813

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* ME mid-eye, HP hypural plate,
FT fork of tail, TS tip of snout.

Table A2. Mean lengths weights, and condition of development for the samples of incubator fry obtained at 25%, 50%, and 75% emergence. *

	Incubator # & Type	S	Temperture Units	N	Mean length (mm)	SD	Mean weight (mg)	SD	Mean Index (kD)	SD
25% Samples	P 11	R	832.8	62	27.2	0.99	152.8	23.59	1.96	0.06
	P 14	R	832.8	59	27.6	0.96	161.3	20.82	1.97	0.04
	E 3	R	823.9	56	27.1	0.83	156.3	20.01	1.98	0.05
	E 4	R	823.9	51	27.5	0.66	159.7	15.23	1.97	0.04
	P 12	A	837.2	57	27.5	1.04	158.0	23.3	1.96	0.04
	P 13	A	850.6	50	27.7	0.91	161.1	20.16	1.96	0.03
	E 5	A	823.9	49	27.2	0.96	150.3	22.6	1.95	0.05
	E 6	A	823.9	49	27.4	1.08	157.8	22.09	1.97	0.05
	P 17	I	850.6	57	27.4	0.99	152.3	21.09	1.94	0.04
	P 19	I	850.6	60	27.7	0.93	159.1	18.95	1.95	0.03
	E 1	I	823.9	42	27.1	0.89	154.6	18.62	1.97	0.04
	E 2	I	823.9	48	27.2	0.78	156.7	17.04	1.98	0.04
50% Samples	P 11	R	837.2	57	27.3	0.93	151.4	20.82	1.95	0.04
	P 14	R	841.7	48	27.7	0.92	160.9	25.53	1.96	0.06
	E 3	R	850.6	50	27.3	0.89	153.1	18.81	1.96	0.04
	E 4	R	850.6	50	27.5	0.83	153.7	17.68	1.95	0.04
	P 12	A	850.6	49	27.5	0.88	161.0	18.65	1.97	0.04
	P 13	A	859.4	54	28.0	0.77	168.4	20.13	1.97	0.04
	E 5	A	890.6	61	27.5	0.99	143.0	18.19	1.90	0.05
	E 6	A	850.6	50	27.7	0.90	159.3	19.04	1.96	0.04
	P 17	I	863.9	51	27.8	1.06	157.4	22.38	1.93	0.04
	P 19	I	859.4	62	27.5	0.88	152.1	18.74	1.94	0.04
	E 1	I	855.0	50	27.2	0.84	150.9	18.48	1.95	0.04
	E 2	I	855.0	50	27.4	0.82	151.9	19.14	1.94	0.04
75% Sample	P 11	R	850.5	50	27.6	0.99	151.2	22.42	1.92	0.06
	P 14	R	850.5	96	27.7	0.98	157.7	21.35	1.95	0.05
	E 3	R	863.9	49	27.5	0.97	153.7	21.47	1.94	0.04
	E 4	R	863.9	49	27.5	0.84	154.5	18.82	1.95	0.04
	P 12	A	863.9	50	27.5	0.83	158.1	18.05	1.96	0.04
	P 13	A	868.3	56	27.8	0.90	165.9	19.93	1.97	0.04
	E 5	A	900.0	51	27.4	0.92	138.2	18.98	1.88	0.05
	E 6	A	890.6	52	27.8	0.80	161.0	18.50	1.96	0.04
	P 17	I	872.8	62	27.7	0.93	156.0	21.66	1.94	0.04
	P 19	I	872.8	51	27.7	0.84	155.3	19.34	1.94	0.04
	E 1	I	863.9	51	27.4	0.94	155.2	19.31	1.96	0.03
	E 2	I	863.9	50	27.2	0.83	150.4	18.95	1.95	0.04

* Symbols as in Table 2.
N, Number of fry in sample.
SD, Standard deviation of the mean.